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Changes in Mandibular Morphology From the Jomon to Modern Periods in Eastern Japan

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KEY WORDS mandible; chronological change; mandibular reduction; origin of Japanese

ABSTRACT Metric characteristics of the mandibles of modern and various historical populations from the Kanto region (east-central Japan) were compared with those of their possible ancestral populations, i.e., the Jomon population from Kanto and the Yayoi population from northern Kyushu and Yamaguchi (western Japan). The Jomon people were aboriginal Holocene inhabitants of Japan, while the Yayoi skeletal series are considered to largely represent immigrants from the Asian continent. Compared to the presumed ancestral morphology, the mandibles of the modern and pre-modern peoples of Kanto showed a marked narrowing, as well as reduction in the regions of major masticatory muscle attachments. The main cause of this underdevelopment is likely to be a diminished chewing stress, resulting in insufficient stimulation for proper growth of the jaw bone. In contrast, symphyseal height increased compared to the earlier Kanto populations. This may be a reflection of the existence of significant Yayoi genetic contribution in the formation of the modern and pre-modern Kanto populations. On the other hand, the mandibles of the protohistoric to medieval populations of the Kanto region are morphologically closer to Jomon. Therefore, they seem to have been genealogically continuous from the native Jomon people with some degree of gene flow stemming from the immigrants. Am J Phys Anthropol 104:227–243, 1997.

Over the past few decades, a large number of studies concerning the population history of the Japanese have been published. Significant advances have been made in the understanding of regional and temporal variation in human skeletal remains from the Japanese archipelago. Based on these studies, two groups have been proposed as possible ancestors of the archipelago's post-300 BC inhabitants. One is the population of the Jomon period (ca. 10,000 BC–300 BC, hunter-gatherer-fishers). The other is represented by a series of skeletons from the Yayoi period (ca. 300 BC–AD 300) from the northern Kyushu region and Yamaguchi Prefecture (agriculturists) (Fig. 1). There is good evidence to show that the latter group was largely composed of immigrants from the Asian continent or their offspring (Kanaseki, 1955, 1976; Yamaguchi, 1984; Hanihara, 1984, 1985a; Dodo, 1987; Mizoguchi, 1988; Dodo and Ishida, 1988, 1990; Nakahashi et al., 1985; Nakahashi, 1990, 1993; Kim et al., 1993; Matsumura, 1994, 1995). Differences or similarities in skeletal morphometric traits between these groups and the modern Japanese or other populations have been intensively analyzed, and various hypotheses about the formation of the modern Japanese have been proposed (Howells, 1966; Yamaguchi, 1982; Hanihara, 1985a,b, 1987,

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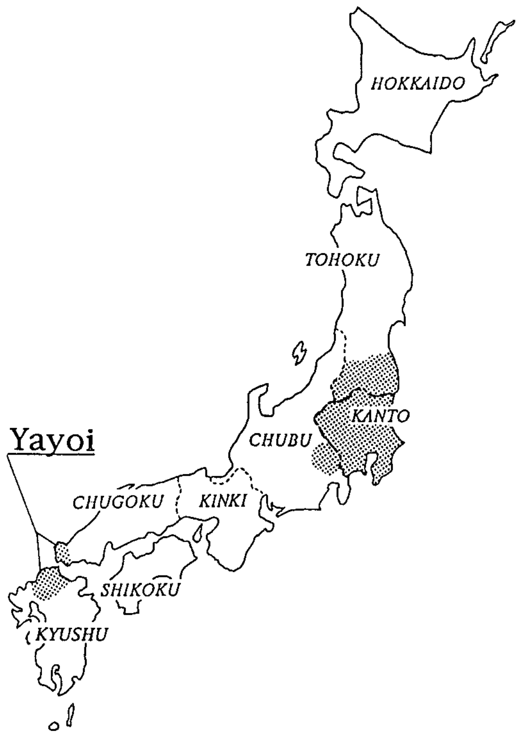

Fig. 1. Map of Japan showing the geographical derivation of the samples used (dotted area). District names are in italics. Yayoi = The Yayoi from the northern Kyushu region and Yamaguchi Prefecture.

1991; Mizoguchi, 1988; Brace et al., 1989, and others). However, because a variety of factors may cause temporal changes in skeletal features, genealogical relationships cannot be distinguished sufficiently from overall morphometric similarities alone. In a detailed investigation, we should take into consideration various causes that may have produced such morphological similarities or differences.

One example of such an attempt is that of Nakahashi (1993), who compared skeletal series of the Kanto and Kyushu regions (Fig. 1) with respect to patterns of temporal changes in cranial morphology and stature since Jomon times. Although there seem to have been broad similarities between Kanto and Kyushu in the pattern of cultural change from the Jomon to protohistoric Kofun periods (see Table 1) as judged from the archeological records, distinct regional differences were detected in the pattern of morphological change. Nakahashi concluded that the most plausible explanation for this discrepancy is gene flow from the Asian continent to the Kyushu region at the beginning of the Yayoi period. Another example is the work by Brace and Nagai (1982), who pointed out a contradiction that occurs when Jomon people are postulated as the direct ancestors of the modern Japanese. If this genealogical relationship is correct, then, contrary to the general tendency seen in Holocene human evolution, tooth size would have had to increase with time. Matsumura (1994) has discussed this in further detail.

The mandible has received much less attention than the cranium in studies of population history despite one potential advantage: its comparatively simpler structure, with relative abundance of functional or biomechanical interpretations (e.g., Hylander, 1984) that permit an evaluation of the influence of varying masticatory environments. The major objective of this study is to examine evidence provided by the mandible that suggests a genetic contribution from Jomon and Yayoi people to the ancestry of post-Yayoi inhabitants of the Kanto region (Fig. 1), while taking into consideration environmental influences on bone morphology.

Morphological comparisons of the mandible were made between Kanto samples derived from various historical periods and their possible ancestral populations, i.e., the Jomon from Kanto and the Yayoi from northern Kyushu and Yamaguchi. Based on the results of these comparisons, I evaluated possible causes of temporal change in the mandibular morphology of Kanto inhabitants. Specifically, an attempt was made to distinguish between those mandibular features that have and have not been affected significantly by environmental factors. Focusing on the latter set of features, I discuss the population history of the Kanto Japanese.

MATERIALS AND METHODS

The materials used in this study and other relevant information are presented in Table 1. The terms Jomon, Kofun, Kamakura, Muromachi, Edo and KMJ are used in this paper to represent mandibular samples from the Jomon to modern peoples of the Kanto region, respectively.

TABLE 1. Materials used in this study (male)

Sample name	Estimated age	Period	Regions[1]	N	Collection
Jomon	4000 BC–300 BC	Jomon	Kanto	58	TUM, NSM St.M, CCC
Yayoi	300 BC–AD 300	Yayoi	Northern Kyushu and Yamaguchi	63	Kyushu Univ.
Kofun	AD 300–AD 900	Kofun (Protohistoric)	Kanto	21	TUM, NSM St.M
Kamakura	AD 1300–AD 1400	Kamakura (Medieval)	Kanto	27	TUM, NSM
Muromachi	AD 1400–AD 1600	Muromachi (Medieval)	Kanto	22	TUM, NSM St.M
Edo	AD 1600–AD 1900	Edo (Pre-modern)	Kanto	38	TUM, NSM St.M
KMJ	AD 1900–AD 1950	Modern	Kanto	24	JSM
MJ	AD 1900–AD 1950	Modern	Outside of Kanto or regions unknown	31	TUM, JSM

[1] Biases occur in the provenances of the specimens within the region. About 90% of the specimens of the Jomon, Kofun, Kamakura, Muromachi and Edo are from the southern part of Kanto. Most specimens of all the samples except the KMJ, MJ and Kamakura are from ordinary burial sites while the provenances of the KMJ were based on documented legal domiciles. Therefore, it may safely be assumed that these provenances largely represent the place of residence of the individuals. In contrast, all but one specimen of the Kamakura sample are from the Zaimokuza site, which is considered to have been a temporary mass burial for war dead. Mikami (1956) argued that a portion of the Zaimokuza specimens probably represents remains of soldiers from other areas in the Kanto region. The Kofun specimens were considered to have derived from a somewhat upper-class people (Terakado, 1981), while the other samples represented more common people (Suzuki, 1969). TUM = University Museum, University of Tokyo; NSM = National Science Museum, Tokyo; St.M = St. Marianna Medical College; CCC = Cultural Properties Center of Chiba Prefecture; JSM = The Jikei University School of Medicine.

The Yayoi is a combined sample of materials from the northern Kyushu region and Yamaguchi Prefecture. Some cranial differences exist between the Yayoi skeletal series of these two regions (Dodo et al., 1992; Matsushita, 1987; Matsushita and Naito, 1989; Nakahashi and Nagai, 1989). The samples were nevertheless pooled in this study because their mandibular metric features are nearly identical (Kaifu, 1995a).

To examine the mandibular morphology of modern Japanese as a whole, another modern Japanese sample (MJ), mostly consisting of specimens with unknown legal domiciles, was included. In addition, KMJ data were compared with published data from 15 Hondo (Main Island) samples from throughout Japan (Commission of Anthropological Investigation of Modern Japanese Crania (CAIMJC), 1981, 1983), for two measurements, bicondylar breadth and least anteroposterior ramus length (BCoB, LAPRL). For these measurements interobserver error was estimated to be relatively small (Koizumi and Kouchi, 1988).

Only males were studied because female sample sizes were too small. For the modern Japanese samples, sex had been recorded in the documents accompanying each individual. The sex of the other specimens was evaluated by the present author primarily on the basis of pelvic morphology. The cranium was used as a secondary source of data for datermining sex.

Selection criteria for the materials were: 1) the presence of a full complement of lower alveoli including that of M3; 2) lower M3 having erupted fully, or at least very near to the occlusal plane; and 3) no marked abnormalities on the lower jaw and teeth (e.g., caries, periodontal disease). Specimens with unilateral alveolar resorption (due to antemortem tooth loss) were included as long as a non-resorbed contralateral alveolus was retained without recognizable side differences of the dental arch as evaluated with the naked eye. The first criterion was adopted because congenital absence of M3 may indicate insufficient growth of the jaw bone in some individuals. Percentages of congenital absence of lower M3 are 5% and 20%, respectively, for Jomon and Yayoi people from the northern Kyushu region (Yamada, 1994), and between 7% and 20% for Kofun, Kamakura, Muromachi and Edo peoples from the Kanto region (Inoue et al., 1982). According to these frequencies, it is unlikely that the results reported here were significantly biased by population differences in frequencies of congenital absence of M3.

Differential age representation of the various samples is another potential source of bias, since the human mandible continues to grow well into adult life (e.g., Behrents, 1990). This factor, however, was considered to be of minimal significance, because of the sample selection criterion concerning antemortem tooth loss. In the KMJ sample ages

TABLE 2. *List of measurements*

Abbreviation	Measurements
1. BCoB	Bicondylar breadth
2. BSnB	Bisigmoid-notch breadth
3. BGoB	Bigonial breadth
4. UML	Upper mandibular length
5. LML	Lower mandibular length
6. BM2B	Dental arch breadth (M2–M2)
7. DAL	Dental arch length
8. CoH	Condylar height
9. LCrH	Least coronoid height
10. LAPRL[1]	Least anteroposterior ramus length
11. SnB	Sigmoid notch breadth
12. SnD	Sigmoid notch depth
13. TCor	Thickness of coronoid process
14. TAng	Thickness of angle
15. MA	Mandibular angle
16. SH	Symphyseal height
17. CCH	Corpus height at C_1
18. P3CH	Corpus height at P_3
19. P4CH	Corpus height at P_4
20. M1CH	Corpus height at M_1
21. M2CH	Corpus height at M_2

[1]Renamed from "least ramus breadth" in Kaifu (1995a).

of the specimens range from 18 to 59 years, with an average age of 32.6 years.

The measurements used in the present study and their abbreviations are given in Table 2, and these are illustrated in Figure 2. Detailed definitions of these have been described elsewhere (Kaifu, 1995a). The least significant difference (LSD) was utilized for the univariate comparisons of the measurements in comparing population pairs (Sokal and Rohlf, 1981). Mann-Whitney's U test was employed for the indices since these are quotients of individual measurements and the distributions of these are not expected to be normal (Hoel et al., 1971).

For further data summary, principal component analysis (PCA) and canonical discriminant analyses were undertaken on selected variable subsets as appropriate. Further remarks on these are given in their respective sections. To summarize and test the major metric trends detected by the univariate analysis, PCA was performed on a subset of the entire battery of variables for which the number of missing observations was sufficiently small. Canonical discriminant analysis was restricted to the evaluation of populations whose mandibular morphology, according to the results of the univariate and PCA analyses, was judged to have been minimally affected through response to changes in the subsistence economy. All

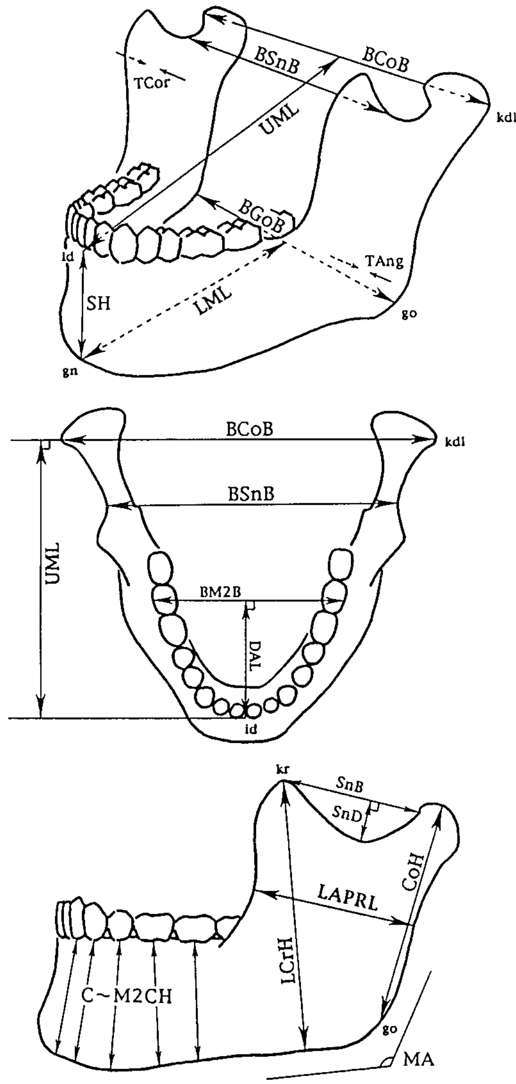

Fig. 2. Measurements used in this study.

statistical procedures were performed using SYSTAT Macintosh 5.2.1 (SYSTAT Inc., 1992) but in the case of Mann-Whitney's U test, Table J of the appendix in Siegel (1956) was used if the sample sizes were less than 20 in both of the populations under comparison.

RESULTS

Univariate analysis

Table 3 shows the descriptive statistics and the results of statistical tests of the individual measurements and indices. Table 4 shows the percentage change of the mea-

TABLE 3. Univariate comparisons of the mandibular measurements and indices

	1. BCoB (Bicondylar breadth)					2. BSnB (Bisigmoid-notch breadth)					3. BGoB (Bigonial breadth)				
				Significance of difference from the mean					Significance of difference from the mean					Significance of difference from the mean	
	N	Mean	S.D.	Jomon	Yayoi	N	Mean	S.D.	Jomon	Yayoi	N	Mean	S.D.	Jomon	Yayoi
Jomon	23	127.6	6.3		0.034*	39	103.7	4.6		0.039*	34	100.1	6.5		0.016*
Yayoi	21	131.4	7.1	0.034		46	105.5	3.9	0.039		19	104.1	7.4	0.016	
Kofun	4	122.7	4.0		0.007*	10	104.3	3.4			4	102.2	6.7		
Kamakura	14	125.8	5.4		0.006*	22	101.8	3.2	0.076*	0.000*	22	102.2	4.8		
Muromachi	17	125.5	4.6		0.003*	19	100.5	3.7	0.006*	0.000*	17	101.3	3.6		
Edo	30	121.0	5.3	0.000*	0.000*	35	99.0	4.1	0.000*	0.000*	35	97.1	5.3	0.032*	0.000*
KMJ	24	121.0	6.3	0.000*	0.000*	24	97.5	4.0	0.000*	0.000*	24	96.9	5.5	0.043*	0.000*
MJ	31	120.6	5.8	0.000*	0.000*	31	98.2	4.1	0.000*	0.000*	31	96.2	6.2	0.008*	0.000*

	4. UML (Upper mandibular length)					5. LML (Lower mandibular length)					6. BM2B (Dental arch breadth at M2)				
				Significance of difference from the mean					Significance of difference from the mean					Significance of difference from the mean	
	N	Mean	S.D.	Jomon	Yayoi	N	Mean	S.D.	Jomon	Yayoi	N	Mean	S.D.	Jomon	Yayoi
Jomon	14	93.3	3.2		0.027*	30	71.9	3.2			48	63.3	2.1		0.000*
Yayoi	21	95.9	2.8	0.027		17	70.9	4.1			51	65.1	2.9	0.000	
Kofun	2	88.2	3.0	0.049*	0.003*	3	68.0	2.0			14	63.6	2.5		0.044*
Kamakura	9	88.2	3.3	0.001*	0.000*	22	72.0	4.3			21	63.1	2.3		0.002*
Muromachi	14	92.5	4.3		0.004*	16	72.8	4.3			19	63.2	2.5		0.004*
Edo	26	93.2	3.5		0.009*	33	69.8	4.2	0.036*		37	62.1	2.7	0.033*	0.000*
KMJ	24	91.4	3.2	0.096*	0.000*	24	68.3	3.8	0.001*	0.034*	24	60.4	2.8	0.000*	0.000*
MJ	31	93.5	3.4		0.014*	31	69.0	4.2	0.005*		31	61.0	2.2	0.000*	0.000*

	7. DAL (Dental arch length)					8. CoH (Condylar height)					9. LCrH (Least coronoid height)				
				Significance of difference from the mean					Significance of difference from the mean					Significance of difference from the mean	
	N	Mean	S.D.	Jomon	Yayoi	N	Mean	S.D.	Jomon	Yayoi	N	Mean	S.D.	Jomon	Yayoi
Jomon	42	34.4	1.8		0.094*	46	62.8	4.2			49	66.4	4.2		
Yayoi	46	35.1	1.7	0.094		44	62.6	3.4			44	64.9	4.3		
Kofun	12	34.2	2.7			8	60.2	4.3			13	62.2	3.1	0.003*	0.060*
Kamakura	20	34.4	2.2			21	61.0	4.3			24	64.0	3.6	0.033*	
Muromachi	16	34.2	2.4			20	60.7	5.1	0.065*	0.085*	22	64.6	4.3		
Edo	37	33.8	2.0		0.003*	34	60.6	4.5	0.019*	0.028*	38	63.1	4.1	0.001*	0.072*
KMJ	24	34.1	1.9		0.054*	24	60.0	3.9	0.009*	0.013*	24	62.9	4.5	0.002*	0.075*
MJ	30	34.9	1.8			31	61.3	4.0			31	64.9	6.0		

	10. LAPRL (Least AP ramus length)					11. SnB (Sigmoid notch breadth)					12. SnD (Sigmoid notch depth)				
				Significance of difference from the mean					Significance of difference from the mean					Significance of difference from the mean	
	N	Mean	S.D.	Jomon	Yayoi	N	Mean	S.D.	Jomon	Yayoi	N	Mean	S.D.	Jomon	Yayoi
Jomon	51	36.1	2.5			39	32.0	3.3		0.098*	37	11.8	1.7		0.000*
Yayoi	52	36.6	2.9			42	33.1	2.8	0.098		41	13.1	1.5	0.000	
Kofun	16	37.4	3.2	0.082		11	31.1	3.0		0.043*	10	12.7	1.5		
Kamakura	25	37.0	2.7			22	30.6	2.8	0.072*	0.001*	22	12.6	1.6	0.057	
Muromachi	22	36.7	2.7			20	32.2	3.7			20	13.2	2.1	0.002	
Edo	38	35.1	2.8	0.076*	0.009*	34	31.7	3.2		0.048*	34	13.2	1.8	0.000	
KMJ	24	34.8	2.5	0.053*	0.008*	24	30.7	2.3		0.002*	24	13.1	1.3	0.003	
MJ	31	34.1	2.5	0.001*	0.000*	31	29.9	2.8	0.004*	0.000*	31	13.3	1.5	0.000	

(*continued*)

TABLE 3. (continued)

	13. TCor (Thickness of coronoid process)					14. TAng (Thickness of angle)					15. MA (Mandibular angle)				
				Significance of difference from the mean					Significance of difference from the mean					Significance of difference from the mean	
	N	Mean	S.D.	Jomon	Yayoi	N	Mean	S.D.	Jomon	Yayoi	N	Mean	S.D.	Jomon	Yayoi
Jomon	48	5.6	0.7			54	5.5	1.1		0.000*	37	119.5	5.9		0.019*
Yayoi	49	5.7	1.0			45	6.5	1.4	0.000		17	123.9	5.8	0.019	
Kofun	16	6.2	1.2	0.033		14	7.8	1.4	0.000	0.003	2	127.5	3.5	0.087	
Kamakura	25	6.1	0.9	0.038		25	7.9	1.3	0.000	0.000	18	117.0	5.9		0.002*
Muromachi	22	5.8	0.8			22	6.3	1.2	0.022		17	121.1	4.0		
Edo	38	5.1	0.8	0.016*	0.002*	38	6.4	1.6	0.003		34	125.5	5.3	0.000	
KMJ	24	5.1	1.0	0.026*	0.004*	24	6.6	1.1	0.001		24	125.1	8.3	0.001	
MJ	30	4.6	0.8	0.000*	0.000*	31	6.6	1.5	0.000		31	124.4	7.9	0.002	

	16. SH (Symphyseal height)					17. CCH (Corpus height at C$_1$)					18. P3CH (Corpus height at P$_3$)				
				Significance of difference from the mean					Significance of difference from the mean					Significance of difference from the mean	
	N	Mean	S.D.	Jomon	Yayoi	N	Mean	S.D.	Jomon	Yayoi	N	Mean	S.D.	Jomon	Yayoi
Jomon	34	31.8	2.3		0.000*	49	31.6	2.2		0.012*	53	31.9	2.3		0.079*
Yayoi	52	34.0	2.8	0.000		59	32.8	2.4	0.012		60	32.7	2.4	0.079	
Kofun	13	32.3	3.0		0.054*	17	31.4	3.1		0.048*	18	31.8	2.9		
Kamakura	21	32.4	3.3		0.023*	26	31.3	2.9		0.013*	26	31.5	2.7		0.040*
Muromachi	17	32.2	2.9		0.018*	19	30.9	2.1		0.004*	22	31.1	1.8		0.008*
Edo	35	33.3	2.5	0.026		37	31.8	2.4		0.063*	38	31.6	2.6		0.025*
KMJ	24	33.9	3.1	0.004		24	32.3	3.0			24	31.8	2.8		
MJ	31	34.0	2.5	0.001		31	32.4	2.2			31	32.0	2.4		

	19. P4CH (Corpus height at P$_4$)					20. M1CH (Corpus height at M$_1$)					21. M2CH (Corpus height at M$_2$)				
				Significance of difference from the mean					Significance of difference from the mean					Significance of difference from the mean	
	N	Mean	S.D.	Jomon	Yayoi	N	Mean	S.D.	Jomon	Yayoi	N	Mean	S.D.	Jomon	Yayoi
Jomon	54	31.5	2.2		0.070*	55	29.9	2.0		0.068*	55	28.1	2.0		
Yayoi	60	32.3	2.5	0.070		59	30.7	2.5	0.068		58	28.7	2.3		
Kofun	19	31.8	2.6			19	30.5	2.5			21	28.9	2.1		
Kamakura	27	31.4	2.8			27	30.4	2.7			27	28.3	2.5		
Muromachi	22	30.8	1.4		0.012*	22	29.3	1.5		0.018*	22	27.3	1.7		0.010*
Edo	38	31.0	2.4		0.006*	38	29.4	2.5		0.006*	38	27.0	2.2	0.014*	0.000*
KMJ	24	31.2	2.5		0.046*	24	29.3	2.2		0.015*	24	26.7	1.9	0.008*	0.000*
MJ	31	31.6	2.4			31	29.7	2.5		0.052*	31	27.1	2.6	0.037*	0.001*

	UML/BCoB (4/1) (Upper mandibular proportion)					LML/BGoB (5/3) (Lower mandibular proportion)					DAL/BM2B (7/6) (Dental arch proportion)				
				Significance of difference from the mean					Significance of difference from the mean					Significance of difference from the mean	
	N	Mean	S.D.	Jomon	Yayoi	N	Mean	S.D.	Jomon	Yayoi	N	Mean	S.D.	Jomon	Yayoi
Jomon	14	74.3	4.8			30	72.3	7.0		0.080	42	54.5	3.4		
Yayoi	21	73.2	5.6			17	68.7	5.6	0.080*		46	54.1	3.3		
Kofun	2	71.2	1.9			3	67.0	6.7			12	53.4	3.8		
Kamakura	9	70.9	3.7	<0.05*		22	70.6	4.8			20	54.6	3.8		
Muromachi	14	73.7	3.8			16	71.9	4.7		<0.1	16	54.1	4.0		
Edo	26	76.6	3.4		0.007	33	72.1	5.4		0.024	37	54.4	3.2		
KMJ	24	75.7	4.2		0.072	24	70.7	6.0			24	56.5	2.6	0.007	0.002
MJ	31	77.7	5.2	0.053	0.003	31	72.1	6.8		0.069	30	57.2	3.9	0.010	0.001

(*continued*)

TABLE 3. (continued)

	SnD/SnB (12/11) (Depth index of sigmoid notch)					CCH/SH (17/16) (Corpus height index)					P3CH/SH (18/16) (Corpus height index)				
				Significance of difference from the mean					Significance of difference from the mean					Significance of difference from the mean	
	N	Mean	S.D.	Jomon	Yayoi	N	Mean	S.D.	Jomon	Yayoi	N	Mean	S.D.	Jomon	Yayoi
Jomon	37	37.2	5.8		0.016*	34	99.8	3.6		0.000	34	101.1	4.6		0.000
Yayoi	41	40.1	5.0	0.016		50	95.9	2.8	0.000*		50	95.4	3.7	0.000*	
Kofun	10	40.4	4.3	0.043		12	96.7	3.4	0.038*		12	96.6	3.9	0.012*	
Kamakura	22	41.6	6.0	0.018		21	97.5	3.4		0.013	21	98.0	4.7		0.005
Muromachi	20	41.1	5.3	0.010		17	96.8	3.7	0.003*		17	97.2	5.5	0.002*	
Edo	34	41.8	6.0	0.006		35	96.1	2.9	0.000*		35	95.5	4.0	0.000*	
KMJ	24	42.7	4.3	0.000	0.059	24	95.3	3.6	0.000*		24	94.0	4.9	0.000*	
MJ	31	44.7	5.9	0.000	0.002	31	95.3	3.3	0.000*		31	94.2	5.3	0.000*	

	P4CH/SH (19/16) (Corpus height index)					M1CH/SH (20/16) (Corpus height index)					M2CH/SH (21/16) (Corpus height index)				
				Significance of difference from the mean					Significance of difference from the mean					Significance of difference from the mean	
	N	Mean	S.D.	Jomon	Yayoi	N	Mean	S.D.	Jomon	Yayoi	N	Mean	S.D.	Jomon	Yayoi
Jomon	34	99.8	5.5		0.000	34	94.7	6.1		0.001	34	89.1	6.9		0.000
Yayoi	49	94.4	4.6	0.000*		48	89.2	5.2	0.001*		47	83.8	6.2	0.000*	
Kofun	12	96.3	5.0	0.094*		12	93.2	5.4		0.016	13	87.4	5.8		0.038
Kamakura	21	97.6	6.4		0.009	21	94.6	7.6		0.001	21	88.4	8.1		0.006
Muromachi	17	96.8	7.1	0.031*		17	91.8	7.8	0.064*		17	85.8	9.2		
Edo	35	93.7	4.8	0.000*		35	88.8	5.7	0.001*		35	81.5	6.4	0.000*	
KMJ	24	92.2	6.0	0.000*		24	86.8	6.9	0.000*		24	79.3	7.8	0.000*	0.020*
MJ	31	93.0	5.7	0.001*		31	87.4	6.6	0.000*		31	79.9	7.6	0.000*	0.065*

Descriptive statistics and the probability levels using LSD (Sokal and Rohlf, 1981) (measurements), and Mann-Whitney's U test (indices). A blank indicates $P > 0.1$. An asterisk on the shoulder of a probability indicates that the mean of the population heading the column is significantly larger than that of the population listed to the left. A probability without an asterisk indicates the opposite.

surements when supposing two cases of direct genealogical relationships, with either the Jomon or Yayoi as the ancestral population.

Comparisons between the hypothetical ancestral populations: Jomon vs. Yayoi. The Yayoi mandibles were revealed to differ from Jomon with respect to seven characteristics (see Kaifu, 1995a,b for details): 1) larger overall size, 2) a higher symphysis (SH), 3) corpus heights that decrease posteriorly in a consistent manner, 4) a relatively low coronoid process (LCrH), 5) a deeper sigmoid notch (SnD), 6) a thicker angular region (TAng), and 7) an open mandibular angle (large MA). In contrast to feature 3), corpus heights at the premolar region of the Jomon mandibles are approximately equivalent to symphyseal height.

Comparisons between the modern samples and the Jomon or Yayoi

Overall size and general proportions. The KMJ and MJ mandibles are small in overall size compared to the putative ancestral populations. Most of the measurements related to mandibular size (1–10 and 16–21 in Table 3) show smaller means in the modern samples.

The KMJ and MJ mandibles are both absolutely (BCoB, BSnB, BGoB, and BM2B in Table 3) and relatively (UML/BCoB and DAL/BM2B in Table 3) narrower than either Jomon or Yayoi. LML/BGoB is an exception to this trend, probably reflecting an underdeveloped angular region of the KMJ mandibles as outlined below.

The ramus and gonial region. The smaller LAPRL and M2CH of the KMJ and MJ indicate that the mandibular angular region in these samples is reduced compared to both putative ancestral populations. The larger mandibular angle (MA) in the KMJ and MJ is possibly related to reduced angular region.

The KMJ and MJ are more like Yayoi than Jomon in having a deeper sigmoid notch (SnD) and a thicker angular region (TAng).

TABLE 4. Percentage difference of means of the measurements from the Jomon (upper) and Yayoi (lower) to the other six populations

	BCoB	BSnB	BGoB	UML	LML	BM2B	DAL	CoH	LCrH	LAPRL	SnB	SnD	TCor	MA	SH	CCH	P3CH	P4CH	M1CH	M2CH
Jomon to																				
Kofun	−3.8	0.6	2.1	−5.5*	−5.4	0.5	−0.6	−4.1	−6.3*	3.6	−2.8	7.6	10.7*	6.7	1.6	−0.6	−0.3	1.0	2.0	2.8
Kamakura	−1.4	−1.8	2.1	−5.5*	0.1	−0.3	0.0	−2.9	−3.6*	2.5	−4.4	6.8	8.9*	−2.1	1.9	−0.9	−1.3	−0.3	1.7	0.7
Muromachi	−1.6	−3.1*	1.2	−0.9	1.3	−0.2	−0.6	−3.3	−2.7	1.7	0.6	11.9*	3.6	1.3	1.3	−2.2	−2.5	−2.2	−2.0	−2.8
Edo	−5.2*	−4.5*	−3.0*	−0.1	−2.9*	−1.9*	−1.7	−3.5*	−5.0*	−2.8	−0.9	11.9*	−8.9*	5.0*	4.7*	0.6	−0.9	−1.6	−1.7	−3.9*
KMJ	−5.2*	−6.0*	−3.2*	−2.0	−5.0*	−4.6*	−0.9	−4.5*	−5.3*	−3.6	−4.1	11.0*	−8.9*	4.7*	6.6*	2.2	−0.3	−1.0	−2.0	−5.0*
MJ	−5.5*	−5.3*	−3.9*	0.2	−4.0*	−3.6*	−1.5	−2.4	−2.3	−5.5*	−6.6*	12.7*	−17.9*	4.1*	6.9*	2.5	0.3	0.3	−0.7	−3.6*
Yayoi to																				
Kofun	−6.6*	−1.1	−1.8	−8.0*	−4.1	−2.3*	−2.6	−3.8	−4.2	2.2	−6.0*	−3.1	8.8	2.9	−5.0	−4.3*	−2.8	−1.5	−0.7	0.7
Kamakura	−4.3*	−3.5*	−1.8	−8.0*	1.6	−3.1*	−2.0	−2.6	−1.4	1.1	−7.6*	−3.8	7.0	−5.6*	−4.7*	−4.6*	−3.7*	−2.8	−1.0	−1.4
Muromachi	−4.5*	−4.7*	−2.7	−3.5*	2.7	−2.9*	−2.6	−3.0	−0.5	0.3	−2.7	0.8	1.8	−2.3	−5.3*	−5.8*	−4.9*	−4.6*	−4.6*	−4.9*
Edo	−7.9*	−6.2*	−6.7*	−2.8*	−1.6	−4.6*	−3.7*	−3.2*	−2.8	−4.1*	−4.2*	0.8	−10.5*	1.3	−2.1	−3.0	−3.4*	−4.0*	−4.2*	−5.9*
KMJ	−7.9*	−7.6*	−6.9*	−4.7*	−3.7*	−7.2*	−2.8	−4.2*	−3.1	−4.9*	−7.3*	0.0	−10.5*	1.0	−0.3	−1.5	−2.8	−3.4*	−4.6*	−7.0*
MJ	−8.2*	−6.9*	−7.6*	−2.5*	−2.7	−6.3*	−0.6	−2.1	0.0	−6.8*	−9.7*	1.5	−19.3*	0.4	0.0	−1.2	−2.1	−2.2	−3.3	−5.6*

*Significant differences at 0.05 level in the statistical test in Table 3.

However, it should be noted that, because of differential development of the angular region, the landmark of TAng (the thinnest point within a 5 mm diameter circle centered at 15 mm from gonion) perhaps was not equivalent among the samples. The coronoid process of the KMJ and MJ is significantly thinner (TCor) than that of either Jomon or Yayoi.

Symphyseal and corpus heights. Despite the general tendency of mandibular size reduction, symphyseal height (SH) of the KMJ and MJ is significantly larger than that of the Jomon and equivalent to the Yayoi.

In the modern samples and the Yayoi, corpus heights decrease posteriorly in a consistent manner, while in the Jomon, corpus heights at the premolar region are approximately equivalent to symphyseal height. This is indicated by corpus height indices (CCH/SH to M2CH/SH) and frequency data of maximum corpus height position (Table 5). The corpus heights of the modern samples are, however, different from those of the Yayoi in that the heights in the posterior region are considerably lower.

From the Kofun to Edo periods

Mandibular reduction. Of the 16 measurements related to mandibular size (1–10 and 16–21 in Table 3), the Kofun, Kamakura and Muromachi are significantly smaller than the Yayoi in 4, 7 and 10 items respectively, and significantly smaller than the Jomon in 2, 2 and 1 item(s) respectively. It is suggested from this that the Kamakura and Muromachi mandibles are smaller in overall size than the Yayoi and rather close to the Jomon condition, but not as reduced as those of the modern populations. Though the Kofun sample is small, these mandibles seem to show a similar trend to that seen in the Kamakura and Muromachi.

The Kofun, Kamakura and Muromachi largely show no tendency of narrowing compared to the Jomon and Yayoi, as judged from the indices of longitudinal to transverse diameters (UML/BCoB, LML/BGoB, and DAL/BM2B). These three populations do not show reduction in the angular region (LAPRL, M2CH, and TAng) and the coro-

TABLE 5. Position of maximum corpus height

	S (%)	C (%)	P3 (%)	P4 (%)	M1 (%)	Total
Jomon	12 (36)	3.5 (11)	9.5 (29)	7 (21)	1 (3)	33
Yayoi	37.5 (80)	3 (6)	3 (6)	3 (6)	0.5 (1)	47
Kofun	8 (67)	0 (0)	1 (8)	3 (25)	0 (0)	12
Kamakura	10.5 (50)	1.5 (7)	4 (19)	3 (14)	2 (10)	21
Muromachi	11.5 (68)	0 (0)	1 (6)	4.5 (26)	0 (0)	17
Edo	28 (80)	1 (3)	4 (11)	2 (6)	0 (0)	35
KMJ	19.5 (81)	2.5 (10)	1 (4)	1 (4)	0 (0)	24
MJ	29 (94)	0 (0)	1 (3)	1 (3)	0 (0)	31

The absolute frequency, and percentage in parentheses. When an individual shows the maximum height on two positions (e.g. C and P3), each position was counted as 0.5.

TABLE 6. Component loadings of the principal component analysis

	Component loadings			
Variables	PC I	II[1]	III	IV
2. Bisigmoid-notch breadth	0.630	0.322	0.451	0.030
6. Dental arch breadth at M2	0.497	0.318	0.598	0.309
7. Dental arch length	0.281	−0.219	0.418	0.460
8. Condylar height	0.706	0.113	−0.347	0.191
10. Least AP ramus length	0.635	0.196	−0.223	0.032
12. Sigmoid notch depth	0.143	−0.390	−0.243	0.696
13. Thickness of coronoid process	0.276	0.582	0.232	−0.422
15. Mandibular angle	−0.319	−0.674	0.467	−0.114
16. Symphyseal height	0.494	−0.731	0.131	−0.267
18. Corpus height at P_3	0.695	−0.582	0.002	−0.345
21. Corpus height at M_2	0.831	−0.068	−0.312	−0.126
Total contribution (%)	29.5	19.3	12.3	11.2
Cumulative proportion (%)	29.5	48.8	61.1	72.2

[1]Plus and minus signs were reversed for convenience.

noid process (TCor). The mandibular angle (MA) of Kamakura and Muromachi is closer to Jomon than to Yayoi.

On the other hand, the Edo shows mandibular size and proportions similar to KMJ. Of the 16 measurements related to size, 8 are significantly smaller than in the Jomon and 12 are significantly smaller than in the Yayoi. UML/BCoB of the Edo shows the narrowing tendency, although DAL/BM2B does not. In addition, the angular region (LAPRL, M2CH, and MA) and the coronoid process (TCor) of the Edo show a marked reduction.

Symphyseal and corpus heights. Although the symphyseal heights of the Kofun, Kamakura and Muromachi are slightly larger than that of the Jomon, their corpus heights are closer to the Jomon condition in both size and proportion (relative heights of the anterior corporal region). In the frequencies of the position of maximum corpus height, they show intermediate tendencies between the Jomon and Yayoi (Table 5). On the other hand, corpus heights of the Edo show a similar trend to that seen in the modern populations.

TABLE 7. Mean component scores

		Mean component scores			
Groups	N	PC I	II	III	IV
Jomon	19	0.28	0.26	−0.10	−0.24
Yayoi	12	0.78	0.28	0.34	0.35
Kamakura	8	0.02	1.05	−0.50	0.16
Muromachi	10	−0.16	0.02	0.02	0.24
Edo	26	−0.36	−0.47	−0.18	0.11
KMJ	24	−0.67	−0.71	−0.40	−0.14

Principal component analysis

In the univariate analysis, it was found that a tendency toward mandibular reduction dominated the post-Medieval populations (Edo, KMJ, and MJ). For further data summary, principal component analysis was performed. Eleven measurements (Table 6) for which sample size was adequate were chosen to represent overall mandibular morphology. The matrix used was the correlation matrix (computed by the pairwise deletion method) of the pooled Jomon to KMJ

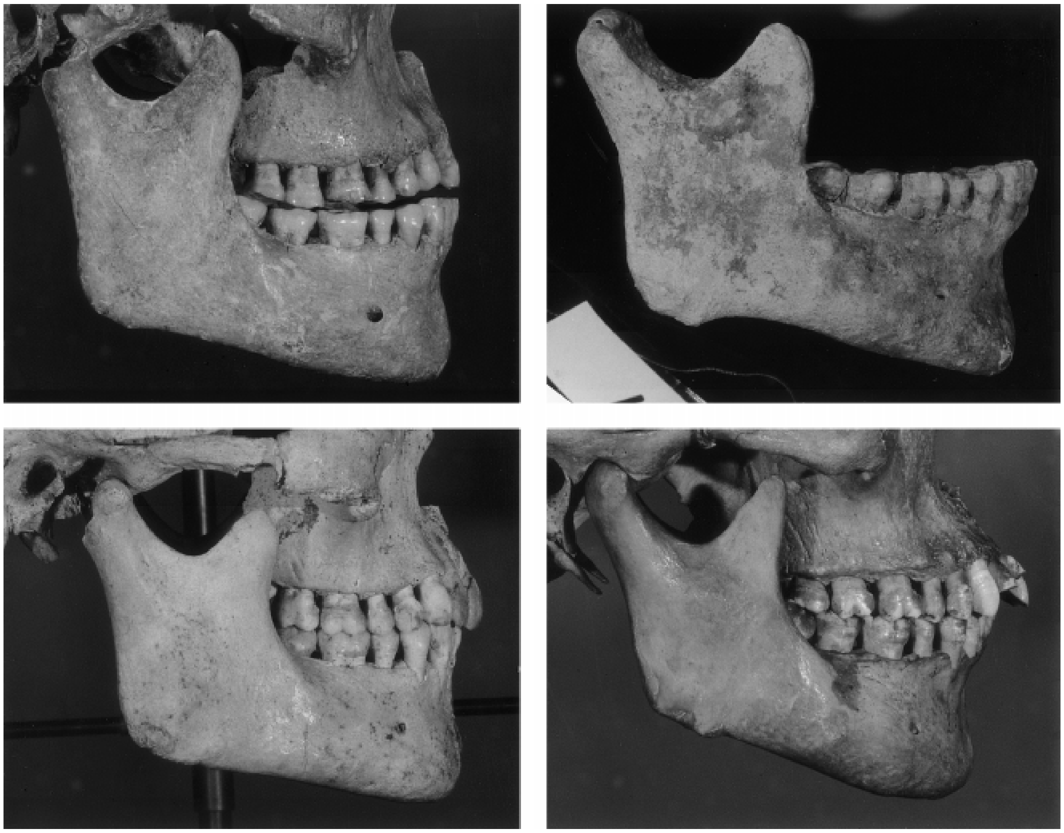

Fig. 3. Representative specimens of Jomon (upper left: 131738, University of Tokyo), Yayoi (upper right: Kanenokuma 288, Kyushu University), Kamakura (lower left: Zaimokuza 139, University of Tokyo), and MJ (lower right: 2106, University of Tokyo) mandibles.

sample, but excepting the Kofun whose sample size was one. Only principle components whose eigenvalue was more than 1 were retained for consideration.

As seen in the component loadings (Table 6), the principal component I (PC I) gives positive scores if mandibular size is large and mandibular angle is small. PC II gives negative scores for those cases having a relatively narrow mandible with reduced mandibular angular region, deeper sigmoid notch, thinner coronoid process, and higher anterior corpus height. As for PC III and IV, extraction of morphologically meaningful interpretations is difficult.

Table 7 shows average component scores for each population. In both PC I and PC II, the KMJ shows the greatest negative scores while Jomon and Yayoi show positive scores. The Edo is close to the KMJ in both PCI and PC II. In PC I, the Kamakura and Muromachi are in between the Jomon and KMJ, and in PC II, closer to the Jomon and Yayoi than to the KMJ. These results are consistent with those drawn from the univariate analysis in suggesting a significant mandibular reduction in the post-Medieval populations, but not in the populations before Medieval times. Representative specimens of Jomon, Yayoi, Kamakura, and MJ mandibles are shown in Figure 3.

DISCUSSION

Direction and cause of the changes leading to the modern condition

From the above comparisons, overall mandibular narrowing and morphological reduction in the areas of major masticatory muscle attachments (size of the angular region and

thickness of the coronoid process) were detected in the modern samples. The present data suggest that in the Kanto region, such a dimensional reduction of the mandible rapidly intensified from the pre-modern Edo period. In contrast to this, the symphyseal height retains its large dimension in the modern samples.

Among the present results, the existence of significant differences in BCoB, BGoB, LAPRL, SnD, TCor, SH and proportion of corpus heights between the Jomon and modern populations partly confirms and provides new documentation of the observations put forward by previous researchers (Ogata and Ishino, 1969, 1973; Suzuki, 1956a, 1957). The interpretation that the mandibles of the modern Japanese are reduced is consistent with that of Inoue et al. (1984), who noticed this phenomenon from a cephalometric study using midsagittal roentgenograms.

It is not clear whether the mandibular reduction seen in the KMJ sample is universal to all modern Japanese populations. However, from a comparison with the data of CAIMJC (1981, 1983), it was confirmed that reduction in bicondylar breadth (BCoB) and least anteroposterior ramus length (LAPRL) occurs throughout various regions among the early 20th century Hondo (Main Island) modern Japanese (the means of BCoB of 15 modern Japanese regional populations range from 120.3 to 125.1, the means of LAPRL from 32.6 to 34.3). Moreover, the mandibular morphology of the MJ sample was virtually identical to that of the KMJ. Such a consistency of trends seen in the KMJ and contemporary samples from other regions seems to increase the reliability of KMJ as a representative sample of the Kanto inhabitants.

The question is, then, what could be the cause of overall narrowing and morphological reduction observed in the KMJ mandibles? Among various possibilities, the most likely primary cause is reduction of chewing stress and ensuing lack of sufficient stimulation for proper growth of the jaw bone, as discussed below.

In the first instance, there is ample documentation that narrowing of the human dental arch occurs due to some environmental factor. Cases of dental arch narrowing within one or two generations have been reported in the human mandible (Corruccini et al., 1983b; Lavelle, 1973) and maxilla (Corruccini and Whitley, 1981; Corruccini et al., 1983a,b; Lavelle, 1973; see Corruccini, 1991 for a review). In addition, in a study of the relative heritability of human mandibular morphology (Watnick, 1977), the angular region was reported to receive the greatest environmental influence.

There is also evidence showing that monkeys raised on soft foods exhibit a similar pattern of mandibular reduction to that seen here in the KMJ sample. A subsample of squirrel monkeys raised on a soft diet showed absolute and relatively narrower dental arches compared to those of the hard-diet subsample (Corruccini and Beecher, 1982). Corpus height at M2 of rhesus monkeys raised on soft foods was significantly lower than that of the hard-diet controls (Bouvier and Hylander, 1981). In addition, a number of controlled experimental studies using rats or mice consistently showed the angular region or ramus to be the portion which showed the most marked dimensional difference between the hard and soft-diet groups (Watt and Williams, 1951; Moore, 1965; Ito et al., 1982, 1988; Inoue et al., 1986; Kikuta, 1985). Although caution is called for in the use of rodents for models of human mastication (Corruccini and Beecher, 1982), this pattern of reduction is also similar to that detected in the KMJ sample.

It is worth noting that chewing stress was reduced in modern Japanese populations compared to those of the earlier historic or prehistoric ages. The main masticatory muscles of modern Japanese may be considered to be underdeveloped in view of the weak development and lack of rugosity of the attachment areas of these muscles. This observation is consistent with findings from an experiment performed by Saitou (1987), who reconstructed diets of the earlier Japanese aristocrats from the Yayoi to Edo periods and experimentally fed these to students. He found that the number of masticatory cycles and chewing time spent decreased with recency of period of the simulated diets. He also made a comparison of consistency of the staple foods (mixture of

TABLE 8. Percent temporal changes of mandibular measurements in Britain, North Africa, Levant and Japan

	Britain[1] (Medieval to 19th century)	Nubia[2] (Mesolithic to MXCh group)	Levant[3] (Natufian to Arab)	Japan (males)	
				Jomon to KMJ	Yayoi to KMJ
BCoB	−3.3			−5.2	−7.9
LML	−3.5	−22.2	−5.0	−5.0	−3.7
LAPRL	−7.5	−13.1	−11.1	−3.6	−4.9
MA	+6.2		+3.1	+4.7	+1.0
SH	+0.6	−2.1	−6.0	+6.6	−0.3
M2CH			−11.1	−5.0	−7.0

Measurement methods are not exactly the same in each study.
[1] Moore et al. (1968), male data.
[2] Carlson and Van Gerven (1977), pooled sex data.
[3] Smith et al. (1984), the Arab is based on male data, while the Natufian contains some female specimens.

several kinds of rice and grain) of each period and obtained similar results. Reduction in the magnitude of dental wear in modern Japanese (Hanihara et al., 1988) is also consistent with this suggestion, although it is important to keep in mind that magnitude of wear may not necessarily correlate with degree of chewing stress.

Furthermore, mandibular reduction in the Kanto region apparently accelerated within a very short period, during the transition from the Medieval to the Edo periods. This rapid tempo of change seems to weaken the argument that natural selection, relaxation of selective pressure, or genetic drift have been the major cause of this reduction.

In a more global context, there are several reports of chronological change of mandibular metric traits similar to that reported above, occurring in Britain, Nubia and the Levant (Moore et al., 1968; Carlson and Van Gerven, 1977; Smith et al., 1984). The percentage change of the available measurements in these cases is shown in Table 8. Significantly, all of these chronological changes occurred synchronously with substantial change of subsistence patterns or development of civilization. Some of the samples in the above-cited studies may not accurately represent the average population in each region or period, and in some regions, genetic continuity between populations may not be safely assumed. The evidence is consistent, however, in terms of overall reduction of the mandibles within short periods. It is likely that the primary cause of the chronological change in these regions was the same as suggested for the Kanto region.

Size of the Jomon and Yayoi mandibles

In light of the presumed effect of masticatory function on mandibular size, the fact that Yayoi mandibles are larger than Jomon seems to be a contradiction in that Jomon people were hunter-gathers while Yayoi people were associated with metalworking and rice agriculture. However, the difference between Jomon and Yayoi with respect to jaw size is consistent with that of tooth size detected by other studies (Brace and Nagai, 1982; Matsumura, 1994). It is reasonable to apply to jaw size the same argument made by these authors in explaining tooth size relationships. That is, the larger mandibles of Yayoi may reflect the long-lasting hunter-gathering subsistence of their ancestors probably in Northeast Asia, and their relatively recent adoption of rice agriculture (as in Matsumura, 1994). On the other hand, the smaller mandibles of the Jomon people may reflect temporally deep culinary practices associated with one of the world's earliest pottery making tradition (as in Brace and Nagai, 1982, and Brace et al., 1989).

Symphyseal height

The analysis presented here strongly implicated environmental change as the cause of temporal change in KMJ mandibular morphology. Accordingly, most of the seven differentiating characteristics between Jomon and Yayoi (see Results) are unsuitable in inferring a relative genetic contribution of these populations to the ancestry of the modern Japanese.

In contrast to this general reduction of the mandible, symphyseal height (SH) shows no reduction in the KMJ sample. Thus SH may indicate affinities among the populations under consideration. In the Kanto region, SH increases abruptly after the Edo period, but what explains this phenomenon? In the Kanto region, estimated stature decreases gradually and size of the neurocranium remains almost constant through historic times (Hiramoto, 1981; Suzuki, 1969). Therefore, change of body and/or cephalic size does not account for the increase of SH.

Among conceivable stresses in the mandibular symphysis during mastication, symphyseal bending due to twisting of the mandibular corpus about its long axis is closely related to symphyseal height (Hylander, 1984). The higher the symphysis, the stronger the mandible becomes against this stress. However, there would have been no mechanical need to increase SH in the modern populations where the chewing stress was reduced. In addition, in the British, Nubian and Levantine populations, SH remains relatively constant through time (or at least increases only slightly), while the other measurements generally show considerable reduction (Table 8). These facts suggest that under an environment which would cause a series of characteristics of mandibular underdevelopment, SH is relatively unsusceptible. Therefore, it seems most reasonable to interpret the increase of SH as the result of a significant genetic contribution from the original Yayoi immigrants to the ancestry of the modern Kanto Japanese.

It is possible that alveolar bone growth accompanying continuous eruption of the lower anterior teeth could increase SH (Dawson, 1989). However, as information relevant to this issue is limited for Japanese skeletal series, a discussion will not be attempted here.

If SH is relatively independent of environmental influences, one might expect this to be reflected in inheritance patterns. A number of attempts have been made to investigate relative heritability of human mandibular morphology using lateral cephalograms (Horowitz et al., 1960; Hunter, 1965; Arya et al., 1973; Watnick, 1977; Saunders et al., 1980; see reviews in Nakata, 1985, and Hunter, 1990). Knowledge concerning symphyseal height seems, however, inconclusive at the present stage, due to lack of standardized measuring techniques.

Protohistoric and historic populations in the Kanto region

The mandibles of the Kofun, Kamakura and Muromachi periods generally showed no morphological reduction. Muscle markings, in my view, are well developed on these mandibles. Thus, for these populations, comparisons based on the seven characteristics which show marked differences between Jomon and Yayoi may be useful in assessing affinities.

Among seven major differentiating characteristics between Jomon and Yayoi (see Results), the Kofun, Kamakura and Muromachi mandibles are generally close to the Jomon in size and gonial angle. However, they are close to the Yayoi condition in depth of sigmoid notch and thickness of angular region, and show an intermediate tendency in symphyseal and corpus heights. Assuming that mandibular reduction due to decreased masticatory stress had not occurred in these populations, their smaller sizes strongly suggest that they were genealogically continuous from the native Jomon people. On the other hand, other features show some degree of similarity to the condition seen in the Yayoi. In addition, I observed that these specimens usually have a thick mandibular basal region below the posterior teeth, which is one of the features differentiating the Yayoi from the Jomon (Kaifu, 1995a).

Canonical discriminant functions between the Jomon and Yayoi were calculated and applied to the Kofun, Kamakura and Muromachi samples. Six corpus heights (SH to M2CH) were selected as variables, because these have been shown to differ markedly between the Jomon and Yayoi mandibles (Kaifu, 1995a,b). Inclusion of other variables results in a significant reduction of sample size. Taking side differences of corpus heights into consideration, only specimens with no missing data for six corpus heights on either side were utilized. The results of the canonical analysis (Table 9) show the Kofun, Kamakura and Muromachi to be largely intermediate between the Jomon and the Yayoi. In addition, each population includes some individuals with a high probability of classification (more than 0.9; calculated using Mahalanobis' generalized distances) to either the Jomon or Yayoi reference samples.

The mandibular morphology of the Edo sample was almost the same as that of the KMJ. Thus, the same conclusion as in the case of the KMJ can be applied to the Edo: significant genetic influence stemming from the Yayoi immigrants is likely.

TABLE 9. *Results of the canonical analysis of corpus heights*

Canonical loadings		Group	Predicted group		Total	$P > 0.9$	
			Jomon (%)	Yayoi (%)		Jomon	Yayoi
SH	0.568						
CCH	0.237	Jomon	25 (76)	8	33	8	0
P3CH	0.093	Yayoi	11	36 (77)	47	0	9
P4CH	0.109	Kofun	5 (42)	7 (58)	12	0	1
M1CH	0.084	Kamakura	12 (57)	9 (43)	21	1	2
M2CH	0.042	Muromachi	5 (29)	12 (71)	17	2	2

Canonical loadings and discriminant classification matrix. The last two columns show the number of specimens with classification probability more than 0.9 for Jomon or Yayoi.

There is general agreement that there was a significant genetic contribution from the Yayoi immigrants to the ancestry of the Japanese (e.g., Yamaguchi, 1982; Hanihara, 1991; Omoto and Saitou, 1997). However, views concerning the amount of this contribution relative to admixture with Jomon natives differ among researchers. One major hypothesis is that the genetic constitution of today's Hondo (Main Islando)-Japanese is predominantly derived from Yayoi immigrants, and was established by the Kofun period (Dodo and Ishida, 1990, 1992; Matsumura, 1994, 1995). Another hypothesis, proposed by Hanihara (1991) and labeled by him as the "dual structure model," emphasizes differences seen in cranial morphology and other biological or cultural aspects between west and east Japan. He stressed less influence of Yayoi immigrants in the Kanto district compared to that in west Japan, and postulated that hybridization of two lineage still continues today.

Studies to date on Kofun, Kamakura, and Muromachi samples from Kanto indicate varying degrees of Yayoi genetic influence on these populations. Interestingly, all nonmetric studies either on crania or teeth suggest an overwhelming contribution (Yamaguchi, 1985; Dodo and Ishida, 1990, 1992; Matsumura, 1994, 1995), as do some metric studies on crania (Yamaguchi, 1987; Ishida, 1992), lower limb bones (Yamaguchi, 1986), and tooth size proportion (Matsumura, 1994, 1995). Nevertheless, the strong Jomon-like elements in cranial morphology often detected in these populations (Suzuki, 1969; Hanihara, 1987; Mizoguchi, 1988; Brace et al., 1989; this study) cannot be ignored. This inconsistency among studies calls for further investigation or re-evaluation of previous studies. For example, results of the nonmetric studies, in which a subjective boundary is set to categorize a continuous trait simply as present or absent, may be influenced significantly by slight shift of the boundary. As for metric studies, appropriateness of certain measurements should be re-examined. Skeletal dimensions can change markedly through plasticity without a genetic contribution from other populations. For example, bizygomatic breadth is known to have been reduced significantly in modern Japanese compared to the possible ancestral conditions (e.g., Nakahashi, 1993). It is very likely that the same argument as in the case of the mandibular reduction applies to facial breadth. Maximum cranial length and breadth also may change because of environmental factors, as suggested by the ubiquitous phenomenon of brachycephalization (e.g., Mizoguchi, 1992).

Based on information concerning army organization during the Medieval period (Toyoda, 1963), it is inferred that the Zaimokuza site, the major source of the present Kamakura sample, was the mass burial of lower-class warriors together with their servants, although a number of females and children also are represented among the burials (Suzuki, 1956b). Historical records speak of people called the Emishi: unruly inhabitants of eastern Japan who very likely were, as were the Ainu, descendants of Jomon (Hanihara, 1990). Given the affinity of the Zaimokuza war victims to Jomon, Brace and colleagues (1989) hypothesized that medieval warrior class people in eastern Japan had derived from the Emishi. It is possible that Zaimokuza warriors do in fact include a large degree of Emishi influence, as emphasized by Brace and discussed by Hanihara (1995). However, an alternative possibility remains that the non-Emishi

people of the Kamakura period in the Kanto area also received a significant degree of Jomon influence as predicted from Hanihara's model of Japanese ancestry (Hanihara, 1991). The identity of the Zaimokuza warriors needs further evaluation. Attempts to answer this question, and hence to address its historical and sociopolitical implications, are handicapped at present by lack of Kamakura skeletal samples representing other classes or segments of the Kanto population.

CONCLUSIONS

The mandibles of pre-modern and modern Kanto Japanese samples exhibited a significant narrowing and reduction in the areas of major muscle attachment compared to their putative ancestral populations. This is interpreted as resulting primarily from underdevelopment caused by environmental changes. Traits affected by this reduction were not referred to in the discussion of Japanese ancestry. On the other hand, the greater symphyseal height of the pre-modern and modern Japanese compared to the earlier Kanto samples is best interpreted as the result of a large genetic influence stemming from the Yayoi immigrants.

Mandibular reduction by environmental change seemed to be minimal in the protohistoric and medieval Kanto Japanese samples. Therefore, their mandibular morphology as a whole is considered to be more indicative of their ancestry. Findings reported here suggested limited genetic contribution from the Yayoi immigrants over the native Jomon heritage at that time.

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